Assessment of Electrical Resistivity Anomalies Caused by Fresh Water Discharge Across the Continental Shelf: Seeps Off North Carolina

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Shallow Water

LONG-TERM GOALS

To determine the impact that fresh water discharge across the continental shelf has on the electrical resistivity structure of bottom sediments and, by so doing, to use electrical measurements to constrain the regional hydrology and the exchange of continentally derived groundwater with the ocean. The strength and spatial distribution of resistivity anomalies caused by fresh water will be used to assess the likelihood of false target identification in mine counter measures, and the degree to which bottom conditions might be misclassified.

OBJECTIVES

- Measuring and quantifying anomalous resistivity structures in a region of continental shelf known to be discharging fresh water into the ocean.

APPROACH

The role of groundwater discharge on margin processes is one that is only beginning to be understood. Estimates of the amount of fresh water discharged from the continent through bedrock and into the ocean vary widely, and while some have suggested it is of a similar magnitude to riverine discharge, this remains a controversial issue. Most work to quantify the distribution and fluxes of fresh water across continental margins has been geochemical: there are few geophysical techniques that are sensitive to the presence of fresh pore water. However, electromagnetic techniques might respond to regions containing fresh water, as the electrical resistivity of the bulk sediment would be increased if the freshening were pervasive. We have seen off northern California regions of several hundred square meters which have extremely high electrical resistivities (for example, whereas normal sediments have resistivities of around 1 ohm-m near the seafloor, we saw values as high as several hundred ohm-m within 1-2m of the seafloor). Although we do not know at this time whether fresh water is responsible for these resistivities, we have carried out modeling based on observations of fresh water beneath the seafloor to show that this explanation is plausible (Hoefel and Evans, in press).

We used the same Canadian towed EM system that we have used in two successful ONR funded cruises, in three areas off North Carolina. The system, which is towed along bottom, provides more or less continuous resistivity-depth profiles along a tow line and so is ideal for providing spatial maps of resistivity variation, whether they are caused by changes in facies conditions or by the influence of groundwater. This is in contrast to other EM techniques which place a remote receiver on the seafloor and transmit to it with a towed source: local heterogeneity in resistivity structure at the length scale we are interested in will act as a source of noise in this kind of survey and will be hard to resolve.

The EM system measures the electrical resistivity of the seafloor which we convert to apparent porosity using empirical relationships and the assumption that the pore water has the same salinity as the near-bottom seawater. If this assumption is not valid, because the pore water is in fact fresher than seawater, then we will underpredict the porosity. In a survey off California, we predicted porosities of less than 15% in a few places close to shore. We know that these locations are immediately north of a shallow anticline system, and so one explanation for our observations has been that the pore water is fresh groundwater that is being channeled to the seafloor through faults associated with the anticline system. In the Californian case we have not been able to prove this model. In order to help determine that any observed anomalies in this survey are caused by fresh water and to place our measurements in the context of regional hydrology, we sampled fluids and took CTD measurements above areas of anomalous resistivity.

Chirp seismic profiles were also run in concert with the EM system. Seismic reflection profiling defines the geometry of sediment bedding, allowing any anomalous EM responses to be placed in a geological context.

WORK COMPLETED

During a five day cruise on the R/V Cape Hatteras, we ran a series of EM and chirp seismic profiles off North Carolina. Our survey focused on areas in Onslow Bay and Long Bay offshore North Carolina. We focused on three areas, all of which were in water depths on the order of 15m.The seafloor off Carolina is typically referred to as ``hard-bottom'' with abundant limestone outcrops.

(1) *Offshore Wrightsville Beach, N.C.*

This area was chosen as a result of discussions with Dr. W. Moore, Dr. S. Riggs, Dr. R. Thieler and Dr. W. Schwabb. High resolution side scan imagery, abundant coring and some seismic reflection profiling have been carried out across the region. Several paleo-river channels cut across the shelf in this area, and there is speculation that some of these channels are hydrologically connected to present day creek systems and may act as conduits for fresh water discharge to the continental shelf. Additionally, a large limestone outcrop has been mapped, and divers have noted discharge from its surface.

(2) *Long Bay Well Sites*

Several shallow wells have been established in Long Bay by Dr. W. Moore's group. In some of these wells, a high porosity unit, at a depth of about 2-4m below the seafloor has been penetrated. Long term temperature logs within these wells show the tidally influenced pumping of groundwater within what is inferred to be a limestone cavern of unknown dimensions. While porewaters within the high porosity unit are saline, our expectation is that such a unit would have a large electrical signature. However, because the wells are occupied, we were unable to tow the EM system directly overhead. We ran within about 100m of the wells, but also ran chirp lines directly over the well sites.

(3) ***Long Bay, Castle Haynes Outcrop***

Several lines were run to the north east of the well sites, where vibra-cores sampled the Castle Haynes aquifer unit outcropping on the seafloor. The Castle Haynes is one of the larger and more regionally important aquifer units supplying fresh water to south-eastern North Carolina.

RESULTS

Although EM operations were limited by two losses and recoveries of the system, we acquired a substantial EM data set in all three areas. The data set is by far the most complex we have collected, reflecting the large variation in bottom conditions from sedimented seafloor to outcropping limestone. Additionally, many signatures of old river beds are seen in the data. On the New Jersey shelf, a typical channel response is an increase in apparent porosity on the 4m and 13m receivers, corresponding to a higher porosity channel fill material. Off Wrightsville Beach, the opposite is seen in several instances (i..e. the apparent porosity decreases within the confines of the channel). Having coincident chirp-seismic profiles will be invaluable in aiding our interpretation of the EM data set as we will be able to unambiguously identify channel sequences and find the corresponding EM signature. While the EM signal of a fresh water bearing channel is predicted to be similar to that we have seen, it is too early yet to conclusively state that fresh water is responsible.

IMPACT

The loss of continental groundwater to the oceans is a potentially important area of research both from an oceanographic and from a societal viewpoint. Thus, the use of EM surveys to identify groundwater discharge will be of fundamental importance, not only to the Navy in its mine counter measures efforts, but also to a large geological and hydrological community seeking to understand the exchange of groundwater with the oceans. To date, there is a lack of geophysical constraint on this process, since few methods have direct sensitivity to the presence of fresh pore water. If our survey is successful, it will open up a new avenue of exploration.

RELATED PROJECTS

I have been funded by NSF to develop a towed EM capability at WHOI, and work is underway on the construction of a similar instrument to that operated by the geological survey of Canada.

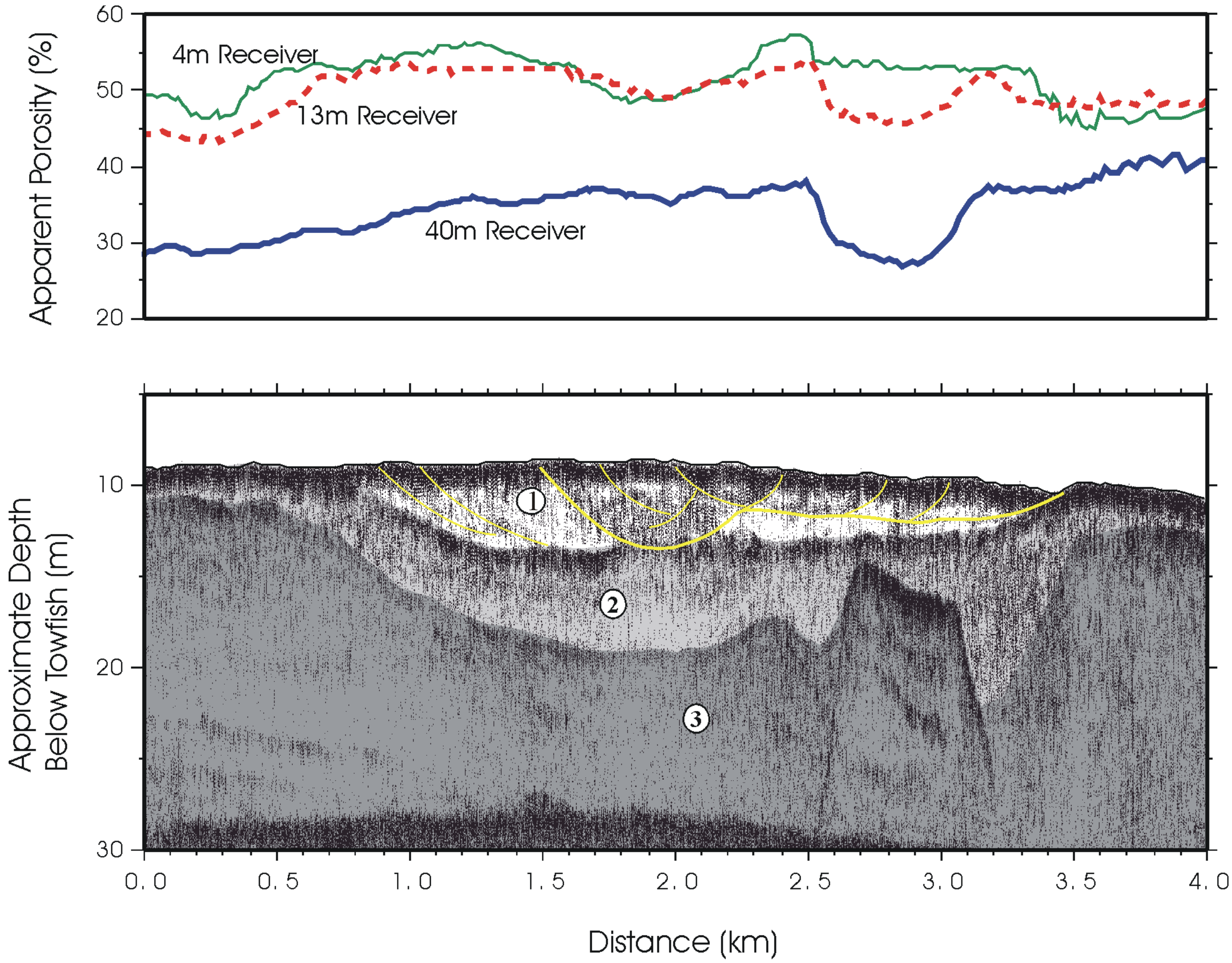
Additional support was provided by the Rhinehart Coastal Research Center at WHOI to carry out a series of land-based resistivity profiles along Wrightsville Beach in an effort to tie channel sequences seen offshore to onshore creek systems. A week post-cruise was spent on Wrightsville Beach, and further work is planned for later this year.

In September, we installed a resistivity meter in two shallow wells in Long Bay. This meter was left in each well for approximately 1 day in order to measure tidal variations in pore water conductivity resulting from exchange with groundwater. This work was carried out in collaboration with Dr. W. Moore.

PUBLICATIONS

Evans, R.L., L.K. Law, B. St. Louis, S. Cheesman, Buried paleo-channels on the New Jersey continental margin: channel porosity structures from electromagnetic surveying, Marine Geology in press.

Hoefel, F and R.L. Evans, Impact of low salinity porewater on seafloor electromagnetic data: a means of detecting submarine groundwater discharge ? Estuarine, Coastal and Shelf Science, in Press.



Figure

Coincident EM and chirp seismic reflection profiles collected on a south-north line in Long Bay. Top: apparent porosity profiles. Bottom: Interpreted chirp seismic reflection profile. The seismic data reveal three main units within a long-lived channel system. The uppermost unit consists of cross-bedded channel deposits, most probably sands with a porosity of 50-55% and resides in the depression of an older shelf channel. The upper unit pinches out on either side of the section as witnessed by the sharp drop in the 4m porosity at 0.4km and 3.3km along profile. The 4m receiver also indicates a drop in porosity at 2km, the location of a prominent paleo-channel within this unit, as well as a punctuated porosity high near 2.4km, perhaps the location of the last active small channel in this system. The top of the second unit is a smoothly eroded surface, probably limestone, deposited on a rougher underlying unit, also probably limestone. The prominent feature of unit 3, near 2.75km, is highly reflective at its surface, and most likely consists of a dense limestone that was resistant to weathering, This feature shows clearly in the response of the 13m and 40m receivers, commensurate with its depth of around 5m below the seafloor and with it being a dense limestone cap. Note, however, that while unit 3 appears to shoal around 3.6-4km, the 40m receiver shows a steady increase in porosity, indicating that this reflector may be caused by a different geology.